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A NEW PULSE GENERATOR CIRCUIT

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(Plate IV)

ABSTRACT. A new pulse generator circuit is described. It delivers a synchronizing pulse, a short time before the main pulse, at a separate terminal for synchronization of the time-base of the oscillograph, with which it is intended to be used. The pulses are approximately triangular in shape. The efficiency of synchronization attained in this work is believed not to have been reached before.

The pulse repetition frequency, the time separation between the synchronizing pulse and the main pulse, the main pulse duration and amplitude are all easily adjustable over a wide range. The circuit can also be used as a two pulse oscillator with slight modifications.

The potentialities and convenience of such a circuit as a tool for development of G.M tube circuits, as a primary pulse source for ionospheric radio-sounding apparatus, as a pulse generator for stimulating muscles and nerves for physiological experiments is also discussed.

INTRODUCTION

The pulses given by a Geiger Muller tube usually pass through certain circuits (amplifying, scaling and recording) before their presence are indicated and their number recorded. As the pulses come at irregular intervals, and are of very short duration, they cannot be well visualised or photographed from a cathoderay oscillograph record because the intensity obtainable from a single trace is very small (Stever, 1942, Dasgupta, 1942). The performance testing of Geiger Muller tube circuits become difficult and one has to rely solely on very indirect methods for estimating the performance. Fault finding becomes still more difficult and circuit development that may be suggested from a visual inspection on the oscillograph screen, of the pulse and its effects, as it goes through different stages and operates on the various circuit elements—is now out of the question. A pulse generator (Manning and Young, 1942) capable of producing short duration pulses in a regular sequence, so that successive traces on the oscillograph screen may be superimposed by proper synchronization with the time-base, is therefore supremely important as a tool for circuit testing and development. Such a pulse generator has many other uses, in various other branches of science, besides the one outlined above.

While developing such a pulse generator—an electron tube circuit—it was observed that for obtaining good photographs of the very sharp pulses that the circuit was delivering, long exposures will be required on the usual types of oscillograph. For prolonged exposures it is necessary that the pattern does not move about the screen because of imperfect synchronization with the time-base of the oscillograph. A forced synchronization of the oscillograph time-base with the pulse generator is therefore clearly necessary. A synchronizing pulse

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must therefore be fed to the synchronizing terminal of the oscillograph time-base. To trip the time-base effectively, it must have the proper polarity. Further, in order that the pulse pattern may come on a convenient position, the synchronizing pulse should also be properly timed with respect to the main pulse.

The usual method of generation of the saw-tooth wave required for an oscillograph time-base, consists in charging a condenser at a constant rate (by a constant current device like a pentode) and of periodically discharging it very rapidly by means of a trigger circuit, thyratron, etc. Forced synchronization of these time-bases is achieved by initiating the condenser discharge at the proper moment by the synchronizing pulse. If the main pulse (the pulse that is to be observed) is used for synchronization, and if synchronization is actually achieved, the one which is synchronizing cannot be examined properly, because it occurs when the time-base condenser is discharging, during the flyback—the high speed return stroke—of the oscillograph light spot. Pulse patterns will appear on the forward stroke if the time-base operates at a frequency that is a submultiple of the pulse frequency. If the ratio of pulse frequency to time-base frequency be n, then there will be $(n-1)$ pulses visible on the screen, the nth tripping the time-base and falling on the return stroke.

However the locking of the time-base in this type of operation is not and cannot be sufficiently positive because the synchronizing voltage must be kept smaller than a certain limiting value, as otherwise instead of the nth pulse tripping the time-base every time, the $(n-1)$th one will be sometimes tripping it, depending upon the relative wavering* of the time-base and pulse generator frequencies. If the synchronizing voltage is increased still more, the time-base will be tripped generally by the $(n-1)$th pulse and both the nth and $(n-2)$th will be tripping it sometimes. As regards steadiness of pattern nothing is achieved by increasing the synchronizing voltage beyond this limiting value. With this type of operation, maximum steadiness is usually attained by making the time-base frequency just lower than half the pulse repetition frequency, in which condition maximum synchronising voltage can be used. We then get only one pulse pattern on the screen, about half-way in the forward stroke. Every second pulse is superimposed upon the one before and we thus get only half the brightness that is available if every one is superimposed upon the other. The phenomenon that the pulse may start, in an electrical, mechanical or physiological system, can be studied only in the later half of the forward stroke, and thus half of the screen space or observation period remain unexploited.

This difficulty can be avoided if a separated synchronizing pulse be fed to the oscillograph time-base just before the main pulse.† Two pulses separated

* The unsteadiness of the time base and the pulse generator is due to main voltage fluctuations, spontaneous fluctuations in the values of certain circuit components—*e.g.*, a resistance, a tube characteristic, etc They are always present, as otherwise forced synchronisation would have been unnecessary.

† Marshall and Talbot (1940) describe[8] a circuit in which a separate pulse is generated from a primary pulse, after a desired time interval.

by a time-interval may be generated from a single pulse if that pulse be first taken direct and then through a delay network. The difficulties of design, and the complication of construction, of a suitable delay network, that will not itself deform the pulse shape and that will readily introduce the different order of time-delays that may be necessary, will be easily understood by one who had the occasion for doing it.

The circuit devised by the author produces two pulses separated by a time-interval. These pulses are quite separate from each other and are obtained from different terminals. Their characteristics—amplitude, duration and shape—may be independently controlled. The time-separation between the two pulses may also be adjusted over a wide range. The same applies to the repetition frequency.

Positive synchronization of a very high order has been achieved—to the extent that the time-base controls may be varied at will to produce a wide range of spot velocities, without in any way affecting the synchronism. Such a powerful synchronization can be achieved only if the synchronizing pulse is separate, single and sharp.

The production of separate and sharp synchronizing pulses allows one to use a single-stroke time-base in place of the continuous running ones. With a single-stroke time-base the synchronizing problem does not arise at all.

The complete diagram of the circuit is given in Fig. 1. The circuit con-

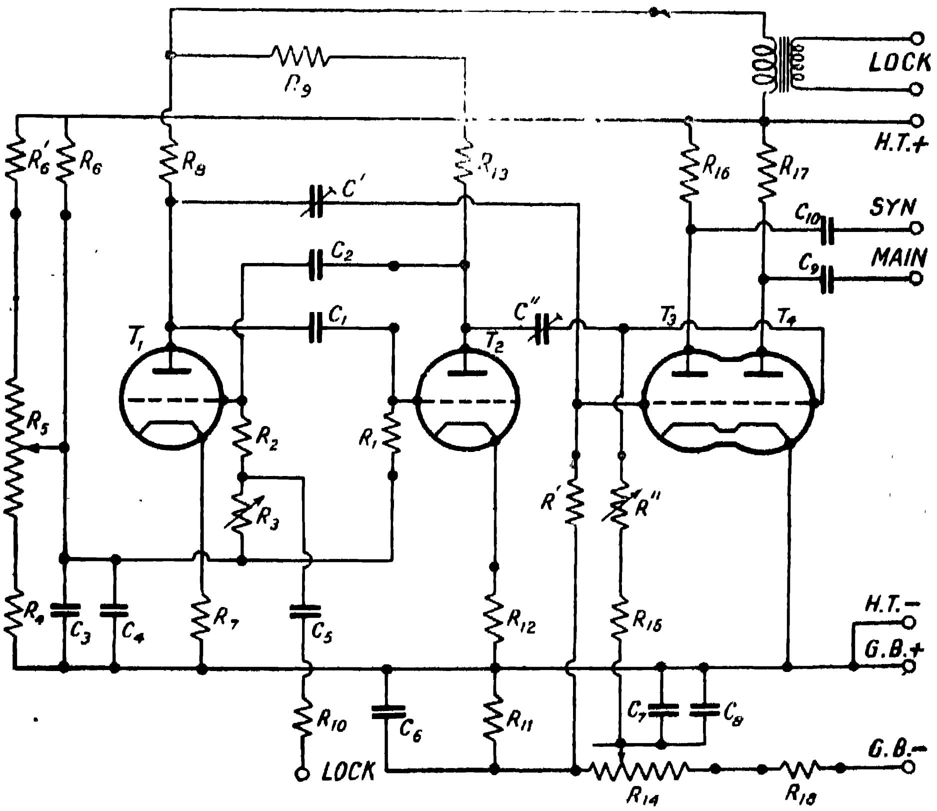


FIG. 1

sists of three parts : an unsymmetrical multivibrator, two pulse generating networks and two pulse amplifiers biased beyond cut off.

RESISTANCES

$R_1 = 1$ Meg ; $R_2 = R_6 = R_{10} = \frac{1}{2}$ Meg ; $R_3 = \frac{1}{2}$ Meg volume control ; $R_4 = R_{15} = 10{,}000$ Ohms; $R_5 = 100{,}000$ Ohms volume control ; $R_6{}^1 = \frac{1}{4}$ Meg ; $R_7 = R_{12} = 500$ Ohms ; $R_8 = R_{13} = 2500$ Ohms ; $R_9 = 100$ Ohms ; $R_{11} = 50{,}000$ Ohms ; $R_{14} = 50{,}000$ volume control ; $R_{16} = R_{27} = 1000$ Ohms ; $R_{18} = 100{,}000$ Ohms.

R' = variable in steps from 10 Meg ; 1 Meg ; 100,000 Ohms ; 20,000 Ohms $R'' = 2$ Meg volume control.

CAPACITIES

$C_1 = 1$ μf to 20 $\mu\mu$f. variable in steps

$C_2 =$,, ,, ,, ,,

C' ; C'' see text

$C_3 = C_5 = C_6 = C_7 = 0{\cdot}1$ μf non-inductive paper condenser.

$C_9 = C_{10} = {\cdot}01$ μf, 600 Volt non-inductive paper condenser.

$C_4 = C_8 = 10$ μf, 450 Volt electrolytic condenser.

Locking Transformer—step.down ratios 1 : 1 ; 1 : 2 ; 1 : 3 ; 1 : 4, secondary inductance—$\frac{1}{2}$ Henry.

High tension voltage may have a value lying between 100 to 250 volts for satisfactory operation.

Grid bias voltage should lie between 40-70 volts. About half this amount is sufficient if R_{18} is short circuited.

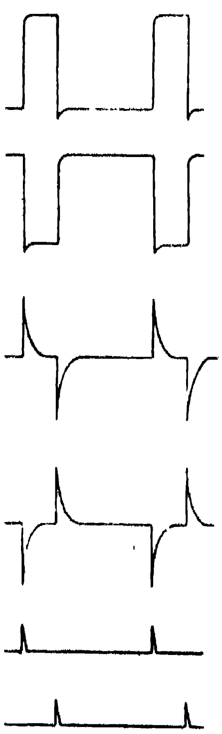


FIG. 2

The wave forms of the anode voltages of the two tubes in the multivibrator (Puckle) is of the well-known shape shown in the Fig. 2.

The pulses that are generated by the pulse generator net-work *CR* and applied to the amplifier tubes T_3 and T_4, are also shown. The mode of operation of the pulse generator net-work is simple. Suppose that the potential applied to the input terminals suddenly change by an amount ΔE. A current i begins to flow through the resistance, controlled by the equation,

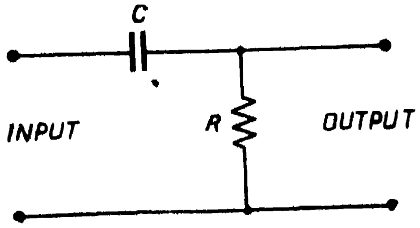
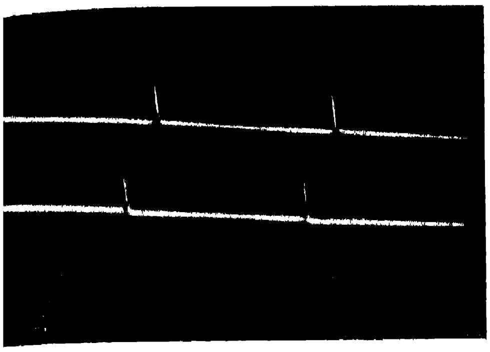


FIG. 3

OSCILLOGRAPH RECORDS

All Photographs taken from Cossor double beam oscillograph Model 339A.
Ten seconds exposure on all photographs.



. 1 The pulse pair as photographed from the ...ograph screen. Repetition frequency = 10,000 , synchronized self running time-base.

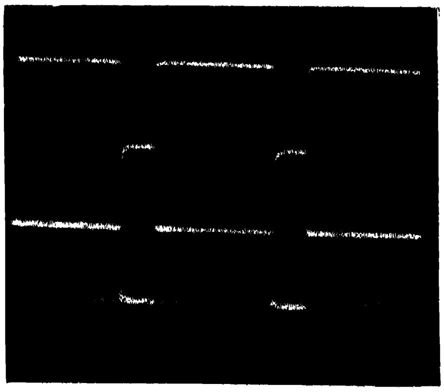
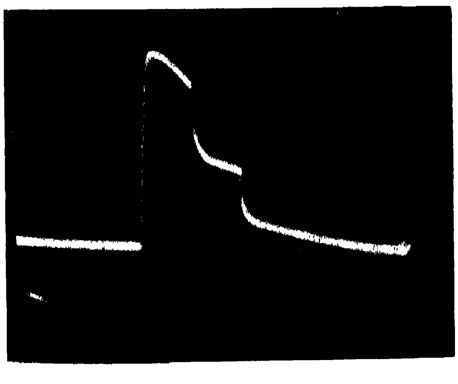


Fig. 2. Anode voltage wave forms of the two tubes in the Multivibrator of the pulse generator. Repetition frequency = 1,000 c.p.s.; synchronized, self running time-base.



... 3. Anode voltage waveform of a hard valve ...M tube pulse recording circuit. Repetition fre...y = 10 c.p.s ; self running time-base.

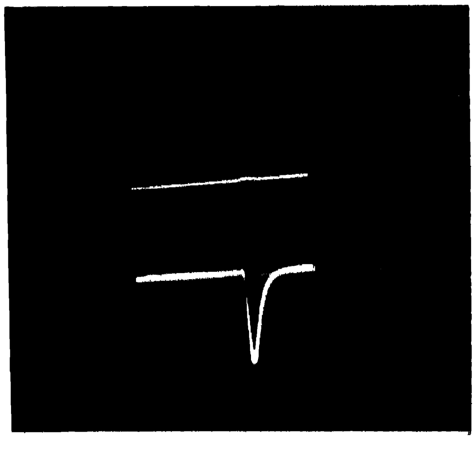


Fig. 4. A two microsecond pulse repeated 70,000 times per second. Single stroke time-base. The time interval from the beginning of the sweep to the start of the pulse corresponds to 6 microseconds.

$$\Delta E = \frac{\int i\,dt}{C} + iR$$

The solution of this equation is

$$i = i_o\, e^{-\frac{t}{CR}} = \frac{\Delta E}{R} \cdot e^{-\frac{t}{CR}}$$

whence, output voltage

$$iR = \Delta E \cdot e^{-\frac{t}{CR}}$$

It is thus seen that for every sharp change in voltage across the input terminals, the pulse generator network produces across its output terminals, a voltage which dies off exponentially and which has a peak magnitude equal to the sudden voltage change. The rate of fall is determined by the time constant CR and may be made as rapid as desired by reducing C and R.

The pulse amplifiers are high μ triodes biased beyond the cut off. Only the tips of the positive pulses get through these amplifiers. As a result they are approximately triangular in shape. Their amplitude, and to some extent the shape, is controlled by varying the bias on the amplifiers. The duration is controlled by varying C and R.

The output pulse from T_3 forms the synchronizing pulse while that from T_4 the main pulse.

The repetition frequency of the multivibrator, and so that of the output pulses, is controlled continuously by varying the grid supply voltage. This is taken from the 100,000 Ω volume control potentiometer connected in the reverse way. The taper in this volume control therefore acts in the reverse direction. Such a method of connection is convenient in the sense that, the frequency changes far more gradually than when it is connected in the normal way. As a result, the adjustment for obtaining a steady picture on the oscillograph screen has become much more easy. This control provides a frequency range ratio of about three.†

The repetition frequency is changed in steps by changing the condenser C_1*.

The relative pulse separation over any range is fixed, *i.e.*, the ratio of the time interval between the synchronizing pulse and the main pulse, to the pulse period, is the same and do not vary with the setting of the repetition frequency control potentiometer. If desired the relative pulse separation may be changed by altering C_2 and R_2. The ratio approximates to $C_2/C_1 + C_2$.

The amplitude (and also shape) of the main pulse is controlled by the 50,000 Ω bias control potentiometer. It adjusts the negative bias on the main pulse amplifier T_4, so as to pass a greater or smaller part of the positive tip of the pulse, that is applied to its grid by the pulse generating network. No such continuous control has been provided for the synchronizing pulse in the circuit described. But if desired such a control can easily be fitted.

*To some extent also C_2.

†If desired, the frequency range ratio may be increased by using a resistor of lower value for R°_6.

The sharpness of the main pulse is controlled by R$''$, a 2 megohm vol. control potentiometer connected as a variable resistance. It adjusts the time constant C$''$ R$''$ of the main pulse generating network continuously. No corresponding control has been fitted for the synchronising pulse, but R$'$ can be changed easily if desired, in steps. C$'$ and C$''$ are trimmer condensers and their capacities may be changed over the range of 5-30$\mu\mu f$ at will. They are kept adjusted to about the maximum capacity.

The 500Ω cathode resistors are for improving the frequency stability and increasing the output voltage. 7A4 triodes are used in the multivibrator and 6N7 in the amplifiers because they proved more than adequate for the author's requirements. Anybody trying to produce pulses of extraordinarily short duration will find 6AG7 television amplifier pentodes better suited than the 7A4 and 6N7 tubes. The 500Ω degeneration resistances may be omitted while anode coupling resistances should be reduced to 1000Ω or less.

A terminal is brought out for injecting a locking voltage for stabilization of the repetition frequency. Locking with a constant frequency source of known value is desirable for accurate measurements in connection with scaling circuits. A transformer for introducing the locking voltage in series with the H. T. is also provided and is also used for the same purpose.

PERFORMANCE

The performance figures are given below. They are by no means ultimate,* and may be extended in both directions by suitable choice of circuit components.

Pulse repetition frequency†	...	Two to 200,000 cycles/second
Pulse separation	...	1/4 second to 2μ second
Pulse duration (Main pulse)	...	100 μ second to 1μ second
(Syn. pulse)	...	500 μ second to 1μ second‡

The generator produces *negative pulses* of 12 volts peak amplitude. This amplitude is sufficient for triggering the single-stroke time base of the Cossor double beam oscillograph (Model 339A) throughout the whole frequency range.

USES

This pulse generator, in conjunction with an oscillograph and an attenuator, may be used for testing, fault-finding and development of pulse amplifying circuits. Linear amplifiers, scaling circuits, recording circuits, etc. may be directly tested and their general performance and shortcomings immediately gauged from the picture that will be obtained continuously on the oscillograph

* The practical limits coincide with the limits of effective resistance coupled amplification.

† If desired the amplitude could be increased to 60 volts peak by using 5000 ohm resistances for R_{16} and R_{17} in place of the 1000 ohm resistances.

‡ A generator designed particularly for low repetition frequencies should preferably omit R_7 and R_{12}, use 50,000 resistors for R_8 and R_{13}, besides using 3 Meg resistors for R_1 and R_2. C$'$ and C$''$ must also be increased in value.

screen. Such a system of testing will show the effect of manipulation of the different controls in the circuit, indicate the presence of A. C. ripple, noise pick-up, microphony, show the net result of frequency, phase and harmonic distortions in modifying the pulse shape, and measure amplification directly on the pulses themselves. Although the response of certain circuits, like linear amplifiers, to pulses of arbitrary shape, may be guessed from an elaborate measurement of the frequency, phase and harmonic distortions, certain other circuits, containing tubes biased beyond cut off, or tubes in which the current or voltage output abruptly begins or saturates, do not lend themselves to even such types of elaborate measurements. But these types of circuits are frequently used in connection with pulses. The pulse generator-attenuator-oscillograph method is the only really satisfactory method of testing the performance of such types of circuits.

As a source of primary pulses for ionospheric or other types of radio sounding apparatus, (Colwell, 1936, Piddington, 1939, Millington and Falloon, 1935), this circuit may represent a revolutionary improvement over the older techniques. Previous workers used mainly some types of thyratron pulse generators. For synchronization of the pulse with the base, they used to synchronize both with the A. C. power supply frequency. The consequences of operating the pulse generator at the fixed unvariable power frequency were a great handicap in low height measurements. (Colwell, 1936, Watson, Watt, etc. 1937). The whole sweep on the oscillograph screen represented quite a long interval of time, some 16 to 20 milliseconds. As a result the dispersion obtainable was very small, not better than 0·1 millisecond, which corresponds to a height of 15 kms. Complicated circuits producing a high velocity sweep at the desired part, were used by Colwell (1936), Haworth (1941) for obtaining better dispersion. Better resolution also demands the production of a short duration pulse, the limit so far reached being 4 μ secs. (Colwell, 1937). A serious and unavoidable defect even with this type of complicated apparatus comes in because of the low repetition frequency, which leads to the reduction of the brilliancy of the trace when the sweep velocity is increased to improve dispersion. The repetition frequency can not be made much greater than the commonly used 50 or 60 c.p.s. as multiple reflections representing long time delays may then come over at the beginning of the second trace producing a confusion with the short delay reflections.

Long delay echoes may be distinguished if the repetition frequency is continuously adjustable, as then a ten per cent shift in the repetition frequency will produce a 10% shift in the position of all the reflected pulses. Long delay "echoes" will thus shift much more than the short delay ones (over the oscillograph screen), and they may thus be distinguished. Synchronization with the power frequency do not allow for such a side experiment.

The pulse generator described in this paper, with its continuously adju-table repetition frequency, its shorter pulse duration, its sharp synchronizing pulse holding the oscillograph time base in synchronism even for considerable variations in the repetition frequency, is a simple solution of all the radio sounding problems associated with ionospheric apparatus. It is therefore expected that it will find wide use in this field.

As a source of pulses for stimulating muscles and nerves for physiological experiments, the circuit probably presents certain advantages.

The circuit may be easily converted into a two pulse oscillator of far greater potentialities than that described by Getting (1937). The only modification is the interconnection of the two output terminals. Getting's circuit uses thyratron relaxation oscillators, tuned and synchronized to the same frequency, but slightly out of step with each other. At each flash of the thyratron a pulse is generated. The two thyratron oscillators that are slightly out of step with each other, produce two pulses separated by a small time-interval. The performance figures claimed for the circuit are, contrasted with my figures

		Getting's circuit.	Author's circuit.
Repetition frequency	=	6,000	2,00,000 c.p.s. max.
Pulse separation	=	20	2 μ sec. min.
Pulse duration	=	5	1 μ sec. min.

The author's performance figures are thus found to greatly exceed that of Getting's. Besides, it will be easily appreciated that the author's circuit permits of quicker and easier adjustments when pulses of different repetition frequency, separation and duration are required.

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